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The impact of the Ischia Porto Tephra eruption (Italy) on the Greek colony of Pithekoussai

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Abstract

The island of Ischia is an active volcanic field, whose activity dates back to more than 150 ka. From Neolithic times it experienced a complex history of human colonization and volcanic eruptions that destroyed settlements and drove away the population. Recent archaeological and volcanological research has demonstrated that humans have periodically had to face volcanic and related hazardous phenomena since at least the Greek foundation of Pithekoussai (8th century BC).

During the 5th century BC a telluric event is reported by the historian Strabo to have caused the abandonment of a Syracusan military outpost on the island. In the volcanological literature the Ischia Porto Tephra eruption has been identified as the most likely culprit. The eruption formed a crater lake in the north-eastern corner of the island and emplaced a poorly dispersed pyroclastic deposit, composed of a sequence of magmatic and phreatomagmatic scoria- and pumice-fallout beds, interlayered with minor pyroclastic density current deposits. Recent excavations furnished clear evidence of the impact of this eruption on a settlement located on S. Pietro Hill, to the east of Ischia's harbour.

The archaeological finds include mounds of building materials, pieces of decorative terracotta panels and a few terracotta antefix fragments. The spatial distribution of the material found, the presence of stacks of tiles and other building materials and the absence of any structural remains, suggest that this was a building site for the construction of a temple. As written sources confirm, although the site and the military garrison were abandoned, the colony survived.

1. Introduction

Combined volcanological and archaeological investigations, carried out through a careful comparison between sedimentary and cultural stratigraphies, have been shown to be a very powerful tool in understanding the impact of volcanic eruptions on past communities and their settlements (Newhall et al., 2000; Siebe, 2000; Lowe et al., 2000; Giaccio et al., 2006; Cashman and Giordano, 2008; Di Vito et al., 2009; Schminke et al., 2009; 2010; Grattan and Torrence, 2010). The new frontier of modern archaeology in volcanic areas moves forward, well beyond the simple cultural interpretation of structural remains and artefacts, with the aim of reconstructing the daily life of past populations, their behaviour in the face of natural disasters, and their resilience to them. In this sense, the pioneering work of Giorgio Buchner at Ischia (Buchner, 1938; 1946; 1969; 1975; 1986) demonstrated that, from Neolithic times onwards, the island has experienced a complex history of human colonization alternating with volcanic eruptions that destroyed settlements and drove away the population. Recent volcanological research and archaeological excavations have demonstrated that volcanism was very intense during the period in which civilization began to gain ground (Buchner, 1986; Gialanella, 1994; de Vita et al., 2010).

From the Greek foundation of Pithekoussai (8th century BC, the first Greek settlement in southern Italy), through the Roman “Aenaria”, up until the emergence of modern Ischia, the history of human life on the island has been closely linked to its volcanic and deformational history (de Vita et al., 2006; Della Seta et al., 2012). During the 5th century BC Ischia fell under the domination of Cumae, which granted the tyrant of Syracuse the right to install a military settlement on the island in return for his help during the war against the Etruscans. The historian Strabo reports that between the 474 and the 466 BC a telluric event forced the Greek colonists from Syracuse to desert this outpost; the Ischia Porto Tephra eruption (IPT; de Vita et al., 2010) has been proposed in the volcanological literature as the best candidate for this role (Buchner, 1986; Civetta et al., 1999). This eruption was characterized by a sequence of magmatic and phreatomagmatic explosions that emplaced scoria and subordinate pumice fallout deposits, interlayered with pyroclastic-surge deposits, and formed a crater lake in the north-eastern corner of the island (de Vita et al., 2010 and references therein). The memory of this event still survived in Roman times, as testified by Pliny the Elder with his *Naturalis Historia* (II, 203), in which he wrote that in the island of *Aenaria* an ancient small-town was swallowed up by the earth - *oppidum haustum profundo* - and a lake was formed following this catastrophe - *alioque motu terrae stagnum emersisse* -. The crater lake formed very close to the coastline, being separated by the sea only by a 20 m wide sandbank, which in 1854 was removed to create the new harbour of Ischia on the initiative of the Bourbon Ferdinand II, King of the Two Sicilies (Buchner, 2004; Carlino et al., 2011).

Archaeological investigations carried out in this area since the first half of the past century, evidenced in fact the presence of a palaeosol at the base of the IPT, containing pottery fragments dating to the 6th-5th century BC, along with many painted roof tiles, considered to be part of a temple (Buchner, 1986).

In order to shed light on the presence and nature of this human settlement, a campaign of archaeological excavations was conducted in advance of work for the construction of a purification plant along the eastern side of the S. Pietro Hill (Fig. 1), which also gave the opportunity to perform a volcanological investigation, aimed at understanding the impact of the IPT eruption on the island's environment and the 5th century BC Greek settlement of Pithekoussai. A total of eight natural and man-made exposures have been recorded in addition to the excavation area, and a detailed stratigraphical and volcanological study was carried out in order to constrain the tephra dispersal area, to reconstruct the eruption dynamics and emplacement mechanisms of the pyroclastic deposits, and to define their interaction with man-made structures and artefacts.

Moreover, the careful *in situ* description of the materials damaged by the eruption and the accurate analysis of each single archaeological find permitted the formulation of well-constrained hypotheses about the use of the discovered site and its historical role in the Greek colonization of Pithekoussai.

2. Geological setting

The island of Ischia is the visible upper portion of a large volcanic complex rising more than 1,000 m above the sea floor in the Bay of Naples (Fig. 1a, b). Together with the island of Procida and the Campi Flegrei caldera, it constitutes the Phlegraean volcanic district, along a NE-SW trending volcanic ridge (Fig. 1a). This district was formed in response to the Pliocene-Quaternary extensional process that generated the Campanian Plain graben, along the Tyrrhenian margin of the Apennine thrust belt (Ippolito et al., 1973; D'Argenio et al., 1973; Finetti and Morelli, 1974; Bartole, 1984; Piochi et al., 2005). NW-SE normal and NE-SW normal to strike-slip transfer fault systems formed during this process, separating the graben into blocks and allowing magmas to reach the surface (Mariani and Prato, 1988; Faccenna et al., 1994; Acocella and Funiciello, 2002).

Ischia is an active volcanic field that covers an area of about 46 km², although geophysical data indicate that the island is the remnant of an older, once larger volcanic complex extending to the west (Orsi et al., 1999; Bruno et al., 2002). Ischia itself is composed of volcanic rocks, landslide deposits, and subordinate terrigenous sediments, reflecting a complex history of alternating constructive and destructive phases due to interplay between tectonism, volcanism, volcano-

tectonism and gravitational surface movements (Vezzoli, 1988; Orsi et al., 1991; 2003; de Vita et al., 2006; de Vita et al., 2010; Della Seta et al., 2012) (Fig. 2).

Volcanism at Ischia dates back to more than 150 ka (Vezzoli, 1988) and continued, with centuries to millennia of quiescence, until the last eruption occurred in 1302 AD. The volcanic rocks belong to the low potassium series (LKS; Appleton, 1972) and range in composition from shoshonite to latite, trachyte and phonolite; the most abundant are trachytes and alkalitrachytes (Civetta et al., 1991). The oldest exposed rocks are part of an eroded volcanic complex, the remnants of which crop out in the south-eastern part of the island (Fig. 2). The products of the subsequent volcanism are small trachytic and phonolitic domes, ranging in age between 150 and 74 ky, which are exposed at the periphery of the island (Fig. 2). A very intense period of explosive activity followed (Brown et al., 2008), predating the large Mt. Epomeo Green Tuff caldera-forming eruption (MEGT; 55 ka; Vezzoli, 1988). This tuff consists mostly of trachytic ignimbrites that partially filled the caldera depression in a submarine environment, and were also emplaced on land outside its margins. The caldera depression was later the site of marine sedimentation, which formed a sequence of tuffites, sandstones and siltstones by the reworking of MEGT.

After the MEGT eruption, volcanism continued with a series of trachytic hydromagmatic and magmatic explosive eruptions up to 33 ka. Most of the vents were located along the present southwestern and northwestern offshore of the island.

Starting from at least 30 ka BP, the injection of new, hotter and less differentiated magma into the system triggered the resurgence of the caldera floor, generating the Mt. Epomeo block, which exhibits a net maximum uplift of about 900 m (Orsi et al., 1991). The resurgent area has a polygonal shape resulting from the reactivation of regional faults and the activation of faults directly related to volcanotectonism (Fig. 2). The western sector of the resurgent block is bordered by inward-dipping, high-angle reverse faults, whose directions vary from N40E to NS and N50W from the northwestern to the southwestern parts of the block. These features are cut by late outward-dipping normal faults due to gravitational readjustment of the slopes. The northwestern and the southwestern sides are bordered by vertical faults with right transpressive and left transpressive movements, respectively (Fig. 2). To the east of the resurgent block, N-S, NE-SW and NW-SE trending normal faults, generated during resurgence, formed a lowland which is connected westward to the resurgent area of Mt. Epomeo through a series of differentially displaced blocks (Fig. 2; de Vita et al., 2006; 2010; Della Seta et al., 2012). This complex structural pattern causes this area to have the highest fumarolic activity and CO₂ fluxes measured on the island, especially along the western border of the resurgent block (Chiodini et al., 2004; Di Napoli et al., 2012).

Volcanism resumed at about 28 ka and continued sporadically until 18 ka, with effusive and both hydromagmatic and magmatic explosive eruptions, that mainly occurred along the southern coast of the island. The resurgence mechanism continued to uplift the Mt. Epomeo block and influenced more efficiently the following volcanic activity, inducing a local stress field that determined the conditions for magma ascent only along the eastern edge of the resurgent block or along regional fault systems (Orsi et al., 1991). The most recent period of activity began at about 10 ka, but volcanism was mainly concentrated at around 5.5 ka and in the last 2.9 ky, with almost all the vents located in the eastern part of the island. Only a few vents are located outside this area, along regional fault systems: these generated a multi-vent lava field in the north-western corner of the island, and a pyroclastic sequence, exposed to the southwest. During the past 2.9 ky, about 30 effusive and explosive eruptions took place: the effusive eruptions emplaced lava domes and high-aspect ratio lava flows, while the explosive eruptions, both magmatic and phreatomagmatic, generated tuff cones, tuff rings and variably dispersed pyroclastic-fall and -current deposits (de Vita et al., 2010 and references therein).

3. The Ischia Porto Tephra

The Ischia Porto Tephra (de Vita et al., 2010) has been observed in a limited number of exposures around the harbour of Ischia, in the north-eastern corner of the island (Fig. 3), over a surface of about 0.8 km². The outcrop area is bounded by the S. Alessandro promontory and the S. Pietro Hill, toward west and east respectively, and the flat lowland at the feet of the Montagnone and S. Ciro hills, toward south and southeast. This area probably represents a structural low, as it is crossed by a N50E trending system of fractures, along which many volcanic vents of the past 2.9 ky have been active (de Vita et al., 2010; Sbrana and Toccaceli, 2011). The oldest rocks, predating the IPT eruption, are lavas exposed along the coast, between the S. Alessandro promontory and the Cafieri beach (S. Alessandro Lavas; de Vita et al., 2010; Fig. 3). They are covered by a reworked deposit containing pottery dating to the 9th-8th century B.C. (de Vita et al., 2010). The IPT directly overlies this deposit in the westernmost outcrops. In the easternmost exposures, at the base of the S. Pietro Hill, a silt deposit with marine fossils and 8th century BC pottery is overlain by a zeolitized tuff deposit, above which a lava flow is well exposed and constitutes the real backbone of the hill (S. Ciro Lavas; de Vita et al., 2010). This unit is covered by a partially reworked and pedogenized ash deposit, which contains pottery dating to the 6th-5th century BC (Buchner, 1986). The IPT directly overlies this palaeosol, and is in turn covered by the deposits of later effusive eruptions that generated a lava flow in the area of S. Alessandro (La Quercia Lavas; de Vita et al., 2010), and a viscous extrusion on top of S. Pietro Hill (S. Pietro Lavas; de Vita et al., 2010). This latter deposit is

partially buried by reworked pyroclastic deposits containing 2nd-3rd century AD pottery (de Vita et al., 2010).

3.1 Stratigraphy

The IPT has been studied in nine stratigraphic sections (Fig. 3), and consists of a succession of slightly dispersed pyroclastic- fallout and -density current beds, reflecting a complex eruption sequence, with a series of explosions that generated phenomena of variable impact on the surrounding land. The juvenile components are both dark-grey pumice fragments with an intermediate degree of vesiculation and black, denser, scoria fragments. They are characterized by the same mineralogical paragenesis throughout the sequence, with slightly variable amounts of feldspar, pyroxene and biotite phenocrysts. Lithic clasts are composed of fresh and altered lavas, and variably hydrothermally altered fragments of tuff.

The IPT has been recognized as the product of a single eruption, whose deposits have been subdivided into three Eruption Units (named A to C from the base upwards) according to their sedimentological features, which allowed the identification of deposits emplaced as a consequence of well defined variations in the eruption mechanism (Fisher and Schmincke, 1984). Eruption Unit B has been subdivided in two Sub-units according to textural and grain-size variations. The type section of IPT has been described along the eastern side of the S. Pietro Hill and is shown in figure 4, along with a synthetic description of the main sedimentological characteristics of each Eruption Unit and Sub-unit. The correlation scheme of all the measured sections is shown in figure 3 .

Eruption Unit A (EUA; Fig 4) is a chaotic and very poorly sorted fallout deposit composed of scoria bombs and lithic blocks, up to 1 m in diameter, with large, lapilli-to-bomb size pumice clasts in an abundant fine fraction, composed of fine-to-coarse ash. This eruption unit is only exposed on the S. Pietro Hill. It attains a maximum thickness of about 2 m, which quickly decreases to zero eastward and southward in a few tens of metres.

Eruption Unit B (EUB) is a sequence of cross-laminated to plane-parallel or slightly laminated, coarse-to-fine ash surge deposits, exposed in all the measured sections, with a maximum thickness of about 2.7 m on the S. Pietro Hill, which decreases radially from the harbour. This unit has been subdivided in two Sub-units (EUB₁₋₂; Fig. 4). EUB₁ is a light-grey, plane-parallel to cross-laminated sequence of alternating fine- and coarse- ash, lapilli-bearing surge deposits, with interbedded two blackish ash layers very rich in peaty material. Lapilli-size clasts are subangular to subrounded grey pumice fragments. This Sub-unit attains a thickness of 70 cm on the S. Pietro Hill, and decreases radially from the harbour, completely disappearing at a distance of over about 400 m. EUB₂ is a slightly laminated sequence of alternating greyish to greenish, clay-rich ash-surge

deposits containing scattered, lapilli size, rounded, dark grey pumice fragments with an intermediate degree of vesiculation and dark, poorly vesiculated, porphyritic scoriae, locally concentrated in lenses and frequently present as ballistic clasts. Their maximum diameter is 15 cm in the exposures near the harbour, and decreases away from it. The thickness of EUB₂ reaches a maximum value of 2.1 m at S. Pietro and decreases radially from the harbour.

Eruption Unit C (EUC; Fig. 4) is a poorly sorted, broadly normally-graded, Strombolian fallout deposit, composed of poorly vesiculated and very porphyritic, welded black scoriae up to 70 cm in diameter, with intercalated thin layered beds of coarse-ash to lapilli-size scoriae. This deposit grades upward into a massive, reddish coarse-ash bed, with scattered bomb-size ballistic scoriae. Lithic fragments are fresh and altered lavas, and hydrothermally altered tuff clasts. EUC is only exposed at S. Pietro, where it attains the maximum thickness of about 4.5 m, and in the north-western corner of the harbour.

According to Rittmann (1930), the areal distribution of IPT, along with thickness and grain-size decreasing of EUB with distance from the harbour, and the very proximal character of EUA and EUC, suggest that the Ischia harbour crater is the vent for the IPT eruption. Within the crater, in an eccentric position relative to the present geometry of the harbour, there is an extrusion of compact lava, which formed a small islet in the lake, probably emplaced during the late stages of the eruption.

3.2 *Eruption history*

Although a detailed and quantitative sedimentological and morphoscopic analysis of IPT is beyond the aim of this paper, on the basis of the macroscopic textural and sedimentological characteristics of the deposits and their variations with the distance from the supposed vent area, it may be hypothesized that IPT is the product of a small volume and low energy phreatomagmatic-to-magmatic explosive eruption. This suggestion is also based on previous studies on the Ischia Porto crater (Rittmann and Gottini, 1980; de Vita et al., 2010; Carlino et al., 2011) and on comparison with similar cases reported in the literature (Wohletz, 1978; Lorenz, 1986; Carrasco Nuñez et al., 2007 and references therein). Three main phases of the eruption can be recognized, each characterized by different eruptive mechanisms and transport-depositional processes of the erupted products (Fig. 5a-d). The opening phase of the eruption was characterized by a “Vulcanian type explosion”, probably triggered by the sudden release of gas pressure due to the heating and vaporization of a surface or (more likely) a very shallow water-table. A transient eruption cloud (discrete thermal; Sparks et al., 1997) was formed, along with the production of a large amount of lithic blocks due to the clearing of the vent (Fig. 5a). Lithic blocks and juvenile spatter and scoria

bombs were emplaced following ballistic trajectories during the continuous fallout of coarse ash from the eruption cloud, forming the very poorly sorted deposit of EUA. Following the explosive steam expansion that caused the vent opening, water, initially driven away by the shock-wave, very likely gained access to the conduit, efficiently interacting with the rising magma and producing the pyroclastic surges of EUB (Fig. 5b). The availability of surface and/or shallow water is testified by the presence of abundant peaty material in the deposits of EUB₁ and the clay-rich layers of EUB₂, which suggests the existence of a marshy environment in the vent area. A progressive increase in explosiveness, due to a more efficient water/magma interaction during this phase of the eruption, is attested by a higher degree of magma fragmentation, recorded by the upward decrease in grain-size at the passage to EUB₂, which is in addition the most widespread deposit of the eruption, forming a tuff-ring around the vent area. Moreover, the passage from the plane-parallel to cross-laminated deposits of EUB₁ to the slightly laminated deposits of EUB₂ very likely accounts for an increasing particle concentration of the transporting medium (Cas and Wright, 1987), which might suggest a larger production of juvenile material in connection with an increased explosiveness during this phase of the eruption. The main phreatomagmatic phase of the eruption very likely caused the vent widening that, combined with a reduced availability of water, determined a change in the eruption style. The eruption of a progressively, pulsating, more degassed and less explosive magma or, as an alternative hypothesis, the reduced magma-water interaction, caused the following Strombolian phase of the eruption with the emplacement of the proximal fallout deposit of EUC. The disappearance of this short-lived eruption column, accompanied by lava fountaining, marked the end of the eruption, which was followed by passive emplacement of the last volumes of magma as a plug within the vent and, probably, the collapse of the vent scarps, as testified by the steep inner slope of the crater preserved in the eastern side of Ischia harbour (Fig 5d). The eruption left a subrounded crater about 400 m in diameter, which was later filled by water, forming a pond very close to the coastline. According to Rittmann and Gottini (1980), the reconstructed geometry of the vent area – with the floor of the crater located below the pre-eruption surface of the surrounding topography, the nature and geometrical characteristics of the deposits that form the edifice, and the characteristics of the eruption, indicate that the IPT crater may be classified as a maar (Lorenz, 1973; 1986; Wohletz and Sheridan, 1983).

4. Archaeological excavations

4.1 Historical framework

In around 770 BC Greek colonists from the cities of Chalcis and Eretria on the island of Euboea settled in the isle of Ischia, which they called Pithekoussai, founding a city of the same name at the

northwest point of the island, with an acropolis on the Mt. Vico headland and the port area and the cemetery in the Sammontano Valley. The settlers found the island already inhabited; the inhabitants, who had occupied several sites near Mt. Vico itself and Castiglione Hill since the 14th century BC, had long maintained trading links with the Aegean, as demonstrated by the remains of Mycenaean pottery found at the Castiglione site (Buchner and Gialanella, 1994). The archaeological excavations conducted in this area, the Sammontano burial ground and the acropolis on Mt. Vico have shown that the indigenous community and the Euboeans initially coexisted and that the island was continually inhabited throughout what is known as the colonial period, but with episodes of local abandonment. Magnificent finds attest to the culture of this period; thriving commerce with the Near East and Eastern Mediterranean is demonstrated by the presence of small exotic objects such as seals and scarabs and the varied pottery types found among the grave goods of some burials. Luxury goods were imported from Greece, particularly from Corinth and Euboea itself, and other finds show that Pithekoussai maintained contacts with Italian regions such as Puglia, Ionian Calabria, Sardinia and, above all, southern Etruria, Latium and nearby Campania. There is also abundant evidence of metallurgy, one of the main factors which – together with trade and pottery production with clay from the island – motivated the colonisation and assured the island's prosperity during the second half of the 8th century BC. On Mezzavia Hill in Mazzola locality the remains of dry-stone buildings were found. These were interpreted as workshops for the processing of bronze and iron, as well as silver and gold. The 8th century BC also saw the greatest expansion of the Greek settlements on the island, as demonstrated by numerous discoveries made on the north coast and in the southwestern part (Buchner, 1986; Gialanella, 1994).

Pithekoussai's progressive decline in importance, which had already begun in the early 7th century BC, was presumably due to the growth of nearby Cumae, of which it became a dominion after the Greek colonists from Pithekoussai, when they finally dared to set foot on the mainland, settled on this natural acropolis that stood by the sea on the Phlegraean coast and dominated the Campanian Plain. Finds of this period are distinguished by the presence of Attic pottery, widespread from the early 6th century onwards due to its clear technical and artistic superiority over all other Greek pottery. Also typical of this period are the numerous fragments of architectural terracottas, which covered the timber structures of temples and other important buildings (Buchner and Gialanella, 1994). The growth of the city of Cumae, with its well-organized port, was seen by the Etruscans as a serious threat to their sea traffic, at a time when overland transport between Etruria and the Etruscan dodecapolis in Campania was becoming increasingly impeded by the Latin peoples (Colonna, 2002). So it was that the Etruscans planned a two-pronged attack, by land and sea, against the Campanian city. However, Magna Graecia was by now a thriving component of

Hellenic expansionism in the Mediterranean and Greek colonies were united by strong ties both between themselves and with their mother country, so that in response to Cumae's cry for help Hiero, tyrant of Syracuse, did not hesitate to send his entire fleet to the rescue of his compatriots. In 474 BC, after the Etruscans' defeat in the naval battle of Misenum, in return for his assistance Hiero was granted permission to establish a military garrison in Ischia, partly in order to control and oppose the movements of the defeated enemies. Between 450 and 420 BC Campania was occupied by Sabellian peoples (the Roman name for Oscan-speaking Italic peoples) from the Apennines of Abruzzo and Molise. In about 420 BC Cumae fell into their hands and became an Oscan city. Only Neapolis resisted the invaders and occupied Pithekoussai, which thus remained a city of Greek culture for a further three centuries (Buchner and Gialanella, 1994).

4.2 *Archaeological finds*

San Pietro Hill has been renowned as an area of archaeological interest since the 1940s, after field-walking surveys conducted for the preparation of Sheet 183 of the Carta Archeologica d'Italia (Buchner, unpublished data). Studies carried out here have shown that the site was occupied since the late 8th century BC (Buchner, 1986), on the basis of the Archaic bricks and architectural terracottas found in a beach deposit overlain by the San Ciro lava (de Vita et al., 2010). Geo-archaeological studies carried out with this work of the eastern portion of San Pietro Hill identified deposits of the IPT eruption as well as, at various points, the lava layers beneath it, which form the basis of the hill and determine its morphology. The surface of the latter lava is complex and slopes downwards from north to south. The numerous irregular depressions in the scoriaceous lava surface are always filled by ash deposits attributable to the IPT eruption. In some cases, at the base of these fills a thin, intermittent and sometimes very pedogenized sandy layer was found, from which the oldest finds recovered during the excavation were obtained. These consisted of several sherds of coarse ware, a grip of triangular cross-section and a partly burnished jar rim, which date to the last quarter of the 8th century BC. Together with this material, above a sandy palaeosol, were found a few fragments of late Geometric Corinthian ware and small spiral-decorated amphorae, similar to those known from the San Montano necropolis (Buchner and Gialanella, 1994).

A much larger quantity of finds was recovered from the palaeosol dating to between the late 6th and first half of the 5th century BC, which is directly covered by the IPT eruption deposit (Fig. 6a-d). These consisted of tiles and roof-tiles with white and brown decorations (Fig. 6a), containers for the storage (*pithoi*) and transport (Corinthian and local amphorae) of food and wine, common wares (jars and *alabastra*), Corinthian pottery and of Ionian tradition, banded pottery (*oinochoai*), table wares (*lekanai*) and kitchen wares (*chytrai*). Most of this material was found in the central, northern

and eastern parts of the site. In the latter area above the palaeosol a small dump of charcoal with mollusc shells was found, together with a large amount of bricks and wall tiles painted in white and brown, *pithoi*, local amphorae, jars, Attic pottery (Fig. 6b), *oinochoai*, *lekanai* and *chytrai*. Several complete tiles were reassembled from the fragments. As well as ceramic materials, the excavations brought to light crumbs of burnt clay and mollusc shells. In the southern part of the excavation a large piece of ridge tile (*kalypter hegemon*) was found in the upper levels. At several points numerous fragments of decorated covering tiles and occasional unpainted antefixes were discovered, together with a single piece of *louterion* rim decorated externally with a white and red braid. A minor quantity of pottery fragments consisted largely of local type B amphorae (Dressel, 1899), type B2 Attic bowls (Villard and Vallet, 1955; Fig. 6c), in addition to *oinochoai*, *lekanai* and small banded bottles, all of local production, and a few fragmentary *chytrai*. Traces of charcoal and a sizeable quantity of mollusc shells were also found (numerous limpet shells, food leftovers) as well as a considerable amount of greenish silt with white streaks – perhaps the remains of the coating of wall-plaster, in which the potsherds were partly contained. To the northwest, underneath several layers of broken tile, a deposit of mud-bricks was found; these had largely disintegrated and were mixed with potsherds. Many small and medium-sized pieces of local grey trachyte were present, as well as occasional large carefully-worked blocks. One of the lower layers contained bones, in part limb bones (probably nonhuman) and half the skull of an equid.

The palaeosol, besides yielding sporadic sherds of common ware and *bucchero* (Fig. 6d), which were scattered on its surface, was cut by several small circular holes and a large pit, attributable respectively to shrubs and a tree (probably olive). At the centre of the excavation there was also a deep open fracture running N-S, in the sides of which an older lava layer could be seen beneath the palaeosol; this formed the base of the hill and was the lowest layer recorded in the archaeological excavation.

A large accumulation of building material was found in the northern part of the excavation, largely composed of middle-sized to large trachyte blocks. In this area the pre-eruption landscape was complicated by the presence of a number of man-made cuts in the palaeosol covering the lavas. The most evident structure was a raised strip, several tens of centimetres in height, oriented approximately N-S and visible for a length of about 20 m. On the upper surface there were numerous horizontal layers of tiles, seemingly stacked up against one another; perhaps this was a temporary deposit of building material. Many tiles were still intact, while others were broken, but could easily be reassembled. In the regions exhibiting most damage, large lava bombs and ballistic blocks ejected during the early stages of the eruption, which had clearly smashed the tiles and

caused the material to slide down the sides of this low bank. The bank itself was also deformed in places due to the impact of ballistic fragments.

5. Discussion

The geological and volcanological study carried out in the area of Ischia harbour, together with the archaeological excavation of the S. Pietro Hill, allowed the reconstruction of the land morphology at the time of the IPT eruption. This area has been inhabited since the 8th century BC; numerous pottery fragments dating to the first half of the century have been found along the northern coast of the island. Fragments of large jars typical of this period and pottery were found in reworked deposits above the S. Alessandro promontory, west of Ischia's harbour, and in beach deposits underneath the S. Ciro lavas, at the eastern end of the harbour (Buchner, 1986; de Vita et al., 2010). Pottery fragments of the last quarter of the 8th century BC were found during this work above these lavas, fixing exactly at this period their time of emplacement. At the time of the IPT eruption, therefore, the study area was characterized by two lava promontories that bounded to the west and east a low-lying area, which was very likely occupied by a coastal marshy zone. The eastern promontory was an almost N-S trending feature that followed the flow direction of the S. Ciro lavas. This had the shape of a finger, with a steep flow front and lateral scarps, and a rough, scoriaceous and articulated surface that reached a maximum elevation of about 15 m a.s.l. The eastern and southeastern slopes of the promontory, probably represented a sea-cliff during the period between the 8th and the 5th century BC, as suggested by the presence of a man-made terrace that follows the N-S to NE-SW trend of the local coastline at that time. At the foot of the southwestern end of this terrace, a compact mud layer buried by the products of the IPT eruption has been found, with a series of circular or elliptical holes, 15 to 30 cm in diameter, here tentatively interpreted as the remnant of a quay structure or mooring poles, located in the innermost part of a small bight.

The trend of cut features and the presence of prominent kerbs or small embankments along the eastern side of the promontory, suggest that the S. Pietro settlement was organized in a series of terraces, as is seen in other colonial period Ischia settlements, such as Mazzola and Punta Chiarito (Buchner and Gialanella, 1994; Gialanella, 1994).

The large amount of building materials found, most of which was typical of that used for temple roofing or decoration, and their spatial distribution and arrangement in tidy stacks or mounds, as well as the presence of a large variety of every-day objects, meal remains and dump mounds within the palaeosol and scattered above it, support the interpretation of this site as a building site for the construction of a temple (or, alternatively, perhaps for the enlargement or restoration of a – as yet

hypothetical – preexisting place of worship).

Against this background the IPT eruption occurred, generating a series of phenomena with variable degrees of impact on the surrounding land and damage to the settlement. Since no human remains have been found in the excavations, it seems very likely that people had enough time to escape before or during the beginning of the eruption and reach safer places. In the first phase of the eruption a heavy fallout of coarse ash and large blocks struck the settlement like a bombing raid, with boulders as large as one metre across impacting the ground. The stacks of roof tiles and bricks were crushed and overturned (Fig. 7), although not displaced greatly, as many tiles were found intact or in fragments that were easy to reassemble. The rolling of the largest clasts down the steep scarps of the hill caused the downslope thickening of the deposit in this phase. The phreatomagmatic phase of the eruption produced pyroclastic surges that, due to the proximity of the vent, had a devastating impact on the settlement, dragging and crushing tiles and ornamental slabs, overturning mounds of materials (Fig. 8), scattering household effects and burying the settlement under a sheet of tephra up to 3 m thick. The small hollow at the southeastern end of the hill was filled in with the pyroclastic current deposits flowing down to the sea, the landing place was completely buried, and new land was probably formed where the S. Pietro beach is presently located, due to the accumulation of the tuff-ring-forming layers. During this phase the main crater was formed and progressively enlarged up to the final diameter of about 400 m, dramatically changing the aspect of the surrounding environment. The presence of a small town or village in the place presently occupied by the Ischia harbour, suggested by the chronicles (Pliny the Elder, N.H. II, 203), cannot be ruled out. In this case it must have been completely destroyed during the formation of the crater, although it seems unlikely that no building remnants or pottery fragments have been found embedded in the pyroclastic deposit.

The last, Strombolian phase of the eruption did not caused additional damage to the settlement, since it was already buried at this stage, and did not have a severe impact on the environment due to the limited extent of the relative deposit, even though the accumulation of welded scoriae and about 4 m of loose pyroclastics caused an increase in the height of the hill.

6. Conclusion

The Greek colony of Pithekoussai in the 5th century BC was declining, most likely because of a series of natural disasters that occurred at the end of the 8th century BC (de Vita et al., 2010), and to the contemporaneous rise of Cuma on the Phlegraean coast. The IPT eruption occurred in the period in which Hiero, the tyrant of Syracuse, had obtained the right to install a military settlement on the island and was trying to revitalize the colony, as the S. Pietro archaeological site bears witness to.

The spatial distribution of the material found in this site, the presence of stacks of tiles and other building materials and the absence of structural remains in the excavated area, suggest that at the time of the eruption this was a building site for the construction of a temple – around which, perhaps, the newborn settlement was being established – rather than the location of an already existing place of worship. The IPT eruption had a devastating local impact, destroying the S. Pietro Hill settlement and modifying the aspect of the surrounding landscape, with the creation of a new lake. As written sources confirm, the site and the building project were abandoned. However, whilst it seems very likely that the Syracusan military garrison was also abandoned, the colony, hardly touched by this episode, survived despite two other volcanic events that occurred soon after the IPT eruption in the area around the crater. S. Pietro Hill was occupied again in Roman times, when a rural settlement was established as demonstrated by the presence of a large amount of amphorae and *dolia* fragments of the 1st century AD, and Italic and African *terra sigillata* of the 2nd and 3rd century AD. Since then the island, despite the occurrence of many other natural disasters, was never completely deserted again, demonstrating the high resilience of the Ischian people, who continued to frequent the IPT crater area, learning to exploit the potential source of wealth offered by hot fumaroles and thermal springs for curative purposes and leisure activities.

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Figure Captions

Figure 1. a) Location map of the study area; b) Digital model of the Ischia volcanic complex (submerged part calculated on the basis of the bathimetric map of de Alteriis et al., 2005); c) Location of the archaeological excavation (red shaded circle).

Figure 2. Geological sketch map of Ischia (modified after Della Seta et al., 2012)

Figure 3. Correlations among measured sections and their location (in the inset). Section n. 9 has been sown in order to evidence the western limit of the IPT dispersal area. Names of the volcano-stratigraphic units are from de Vita et al., 2010.

Figure 4. IPT type section. Pictures show the characteristic of the deposits in the fields (scale as in the stratigraphic section).

Figure 5. IPT eruption history. a) Opening phase; b) Main phreatomagmatic phase; c) Strombolian phase; d) Emplacement of the lava plug within the crater.

Figure 6. Variable kinds of findings of the 5th century BC; a) Painted tiles fragments; b) Attic cups fragments; c) Fragment of *bucchero*; d) Stem of an Attic cup.

Figure 7. Tiles crushed by ballistic blocks during the opening phase of the eruption

Figure 8. Overturned mounds of building materials















